International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 07 | July 2022 www.irjet.net p-ISSN: 2395-0072

ANALYSIS OF CONCRETE FILLED HYBRID FOUNDATION

Aleeda Shaju[1], Neethu Joseph[2]

[1]Mtech Student, Dept. of Civil Engineering, St. Joseph's College of Engineering and Technology, Palai
[2]Assistant Professor, Dept. of Civil Engineering, St. Joseph's College of Engineering and Technology, Palai

---***---

Abstract – *wind power industry has the higher stability and low civil complaints contrast with inland wind farms and also consider as a reliable energy source rather than sustainable energy. These energy systems demand more robust design and execution than the onshore turbine. In this project I am presenting a new concept, i.e. Concrete Filled Hybrid Foundation (CFHF). The CFHF is an improved version of hybrid foundation. The main components of the foundation are double skin monopile, wide shallow bucket and radial stiffeners. The double skin monopile is filled with concrete. The parametric study of various parameters of CFHF is carried out and their maximum horizontal displacement and moment bearing capacity of CFHF is studied in detail. The all parameters will reduce the maximum horizontal displacement and increase the moment bearing capacity.*

***Key Words*: Wind Power, Concrete Filled Hybrid Foundation, , Hybrid Foundation ,Double Skin Monopile, Wide Shallow Bucket And Radial Stiffeners.**

1. INTRODUCTION

The Offshore Wind Power (OWP) industry is one of the fastest growing energy systems in this era. This industry has the higher stability and low civil complaints contrast with inland wind farms and also consider as a reliable energy source rather than sustainable energy. These energy systems demand more robust design and execution than the onshore turbine. Wind is a secondary source of sustainable energy dependents on the sun. The wind velocity and its direction are influence by topographical features, temperature gradient and revolution of the earth.

Currently Europe is the global leader in offshore wind energy sector. The first offshore wind farm (i.e. Vindeby) was installed in Denmark in 1991. According to the Global Wind Energy Council's (GWEC) report the global OWP market capacity grown from 29.2 gigawatt (in 2019) to 35 gigawatt (GW) and the current OWP capacity is 35.3 GW where United Kingdom has 29% of the global installation capacity. "Hornsea Project One" is one of the largest offshore wind projects in United Kingdom which has the capacity of 1.2 GW. According to the statistics the global OWP installation capacity will exceed two thousand gigawatt in 2050. Currently our India has no operational OWP plant but the first one gigawat OWP project was planned in Gujarat. Fig 1 shows the development of the development of wind turbine.

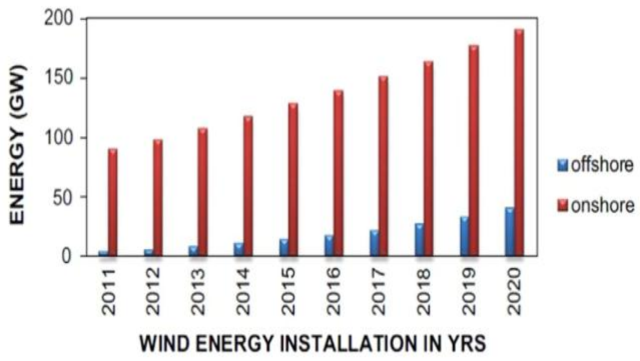


Fig -1: Wind Energy Installations in Years[7]

Selection and design of the foundation control the financial soundness of the project. The investment in installation and design of foundations constitutes 20–30% of the total cost of a typical OWP. The harsh wave and wind environment results higher cost of offshore wind turbine projects than of onshore ones. The selection of suitable foundation depends on type of seabed, installation methods, oceanic climatic condition, water depths, economics, loading characteristics and type of installation equipments etc. Monopile is the most common used foundation in offshore wind industry. It is a simple type foundation consists of large diameter steel tube. Gravity based foundation, monopoles and bucket foundations (known as shallow foundations) used for water depth up to 30m. Jacket foundations are used for water depth up to 60m.These foundations are fixed in seabed and classified into grounded systems. For deeper waters or water depth more than 60m floating system will adopt. Different innovative foundations for offshore wind turbines have been proposed in recent years.

2. FINITE ELEMENT MODELING

Finite Element Analysis is a methods used to obtain numerical solutions of real practical problems. The soil domain is created as continuum model in the software. The dimension of the soil domain is fixed with respect to the dimension of the CFHF. The continuum model is a material model, which contains infinite particle with continuous variation of the material properties. FEA software will solve continuum mechanics problems by subdividing the model into finite elements.

2.2 Validation

In order to validate the method, the finite element analyses of monopile and hybrid foundation are carried out and the obtained results are compared with the journal Chen et.al [1].

2.3 Validation of Monopile

To validate numerical modeling of this project, a finite element analysis of monopile foundation [1] is found and these results compare with present model. In this validation, the diameter of monopile (D1) is taken as 6m and corresponding embedment length (L) is taken as 44.5m.The soil domain diameter is set as 20D1 and corresponding depth is 1.5L. The monopile foundation is modeled with three dimensional eight node linear brick element (C3D8R) and it is made with steel. And normally consolidated silty sand profile with Mohr Coulomb model was adopted for the validation. The properties of monopile and soil domain are given in Table 1.

Table -1: Properties of monopile and soil domain [1]

Soil Properties	Monopile Properties
Youngs modulus : 13.4 MPa	Youngs modulus : 210 GPa
Poisson's ratio : 0.3	Poisson's ratio : 0.3
Cohesion : 32kPa	Density: 78.5 kN/m^3
Friction angle: 27^0	
Unit weight : 8.7 kN/m^3	

The bottom boundary of soil domain is kept as fixed, the horizontal displacements are restrained for lateral direction. Since the geometry of the model is symmetric, only half of the whole model is take for the analysis and the symmetrical constrain is applied to symmetrical plain. The design wind and current load is applied in the form of horizontal load (H), and then horizontal load 3.5 MN is applied at an eccentricity 6 m from the reference point. Weight of superstructure is represented by vertical load (V) and it is taken as 451.5 t. Then the monopile was modeled and analyzed in ABAQUS.

The results obtained from present study and Chen et.al (2020) on monopile foundation are plotted and compared. The moment- rotation graphs of both present study and Chen et.al (2020) shown in Fig -2. The results show some variations (less than 10%) due to the assumptions of unknown data. The comparison between present study and that in the Chen et.al (2020) shows high level of agreement.

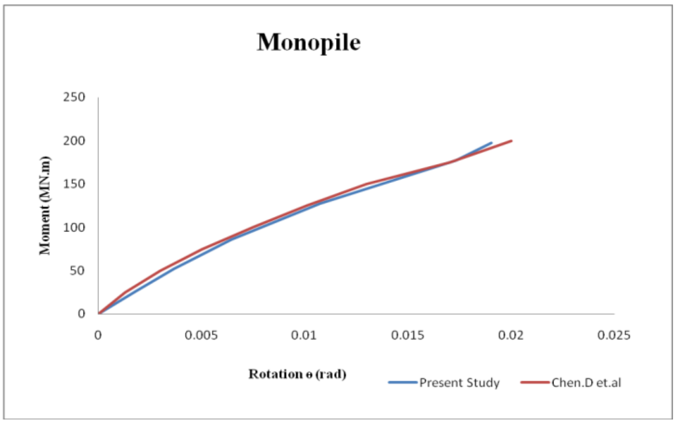


Fig -2: Moment – rotation graph of monopile

2.3 Validation of Hybrid Foundation

Similar to monopile foundation, the finite element analysis of hybrid foundation [1] is found and these results compare with present model. In this validation, the diameter of monopile (D1) is taken as 6m and corresponding embedment length (L) is taken as 25m. The diameter of the wide bucket (D2) is taken as 15m and corresponding embedment length (L2) is taken as 3m. The schematic representation hybrid foundation is shown in Fig.3.. The soil domain diameter is set as 10D2 and corresponding depth is 1.5L1.

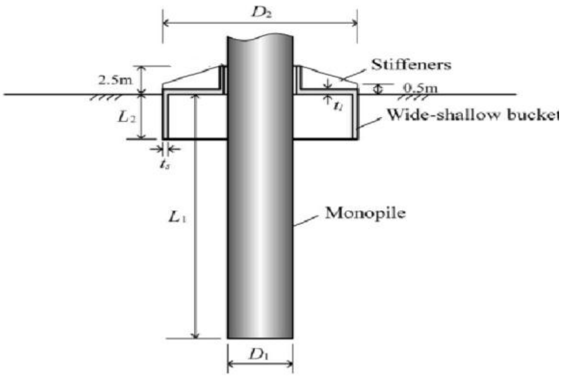


Fig -3: The schematic representation hybrid foundation [1]

The results obtained from present study and Chen et.al (2020) on monopile foundation are plotted and compared. The moment- rotation graphs of both present study and Chen et.al (2020) shown in Figure 4. The results show some variations (less than 10%) due to the assumptions of unknown data. The comparison between present study and that in the Chen et.al (2020) shows high level of agreement.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 07 | July 2022 www.irjet.net p-ISSN: 2395-0072

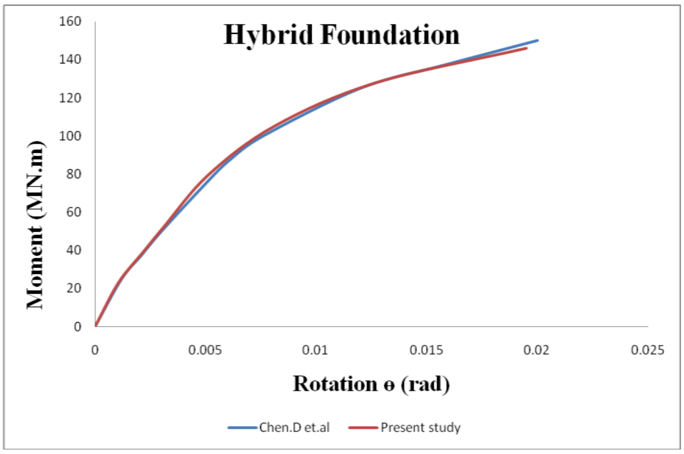


Fig -4: Moment – rotation graph of hybrid foundation

3. CONCRETE FILLED HYBRID FOUNDATION

In this project I am presenting a new concept, i.e. Concrete Filled Hybrid Foundation (CFHF). The CFHF is an improved version of hybrid foundation. The main components of the foundation are double skin monopile, wide shallow bucket and radial stiffeners. The double skin monopile is filled with concrete. The outer part of the double skin monopile surrounded by wide bucket and the stiffeners are arranged in radial pattern and it is located on lid of the bucket. And the concrete s filled in between double s The schematic representation of CFHF is shown in Fig- -5.

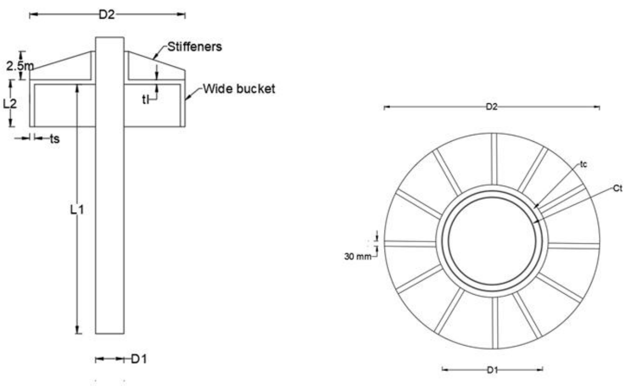


Fig -5: Schematic representation of CFHF

3.1 CFHF Model

The detailed schematic representation of CFHF is shown in Fig.3.6 .Here D1 is the outer diameter of double skin monopile and L1 is corresponding embedment length. Where tp,tl,ts are representing the thickness of monopile, lid and skirts respectively. D2 is the diameter of wide bucket , L2 is the embedment length of wide bucket and Ct is the concrete thickness. A 3 MW turbine is used for present study.

In this analysis soil domain diameter is set as 10D2 and corresponding depth is 1.5L1. The CFHF is modeled with three dimensional eight node linear brick element (C3D8R) and it is made with steel.Fig.6 shows FE meshes of CFHF. And Mohr Coulomb model was adopted for this study.

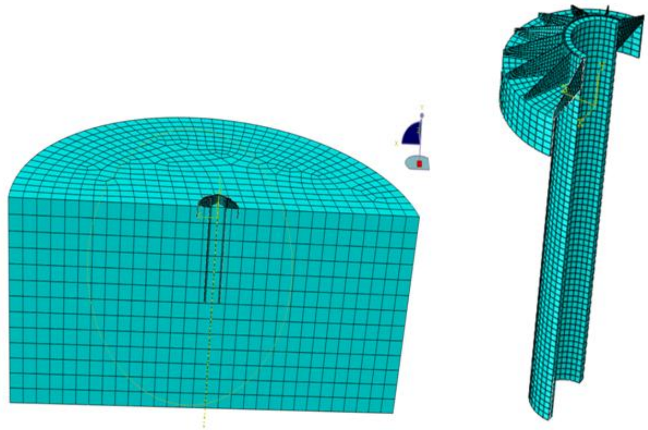


Fig -6: Loads on Monopile Foundation [6]

The bottom boundary of soil domain is kept as fixed, the horizontal displacements are restrained for lateral direction. Since the geometry of the model is symmetric, only half of the whole model is take for the analysis and the symmetrical constrain is applied to symmetrical plain. The design wind and current load is applied in the form of horizontal load (H), and then horizontal load 3.5 MN is applied at an eccentricity 6 m from the reference point. Weight of superstructure is represented by vertical load (V) and it is taken as 451.5 t.

3.2 Parametric Study on CFHF

The parametric study of various parameters of CFHF is carried out and their maximum horizontal displacement and moment bearing capacity of CFHF is studied in detail. The parameters used for the study are diameter of double skin monopile (D1), wide bucket diameter (D2) and concrete thickness (Ct). And thickness of monopile, lid and skirts are kept as fixed throughout the analysis. And embedment length of double skin monopile and wide bucket are also kept as fixed. The range of CFHF parameters selected for the study is shown in the Table 2. And Table 3. shows model names and parameters of CFHF model.

Table -2: Parameters selected for the study

CFHF Parameter	Range Selected
Double skin monopile diameter (D1),	4m to 7m
Wide bucket diameter (D2)	11m to 13m
Concrete thickness (Ct).	0.11m to 1m

Table -2: Parameters selected for the study

Set name	Model name	D1	D2	Ct
Set 1	HFD4d11Ct1	4	11	0.11
	HFD4d11Ct2			0.25
	HFD4d11Ct3			0.51
	HFD4d11Ct4			1
Set 2	HFD5d11Ct1	5		0.11
	HFD5d11Ct2			0.25
	HFD5d11Ct3			0.51
	HFD5d11Ct4			1
Set 3	HFD6d11Ct1	6	11	0.11
	HFD6d11Ct2			0.25
	HFD6d11Ct3			0.51
	HFD6d11Ct4			1
Set 4	HFD7d11Ct1	7	11	0.11
	HFD7d11Ct2			0.25
	HFD7d11Ct3			0.51
	HFD7d11Ct4			1
Set 5	HFD4d13Ct1	4	13	0.11
	HFD4d13Ct2			0.25
	HFD4d13Ct3			0.51
	HFD4d13Ct4			1
Set 6	HFD5d13Ct1	5	13	0.11
	HFD5d13Ct2			0.25
	HFD5d13Ct3			0.51
	HFD5d13Ct4			1
Set 7	HFD6d13Ct1	6	13	0.11
	HFD6d13Ct2			0.25
	HFD6d13Ct3			0.51
	HFD6d13Ct4			1
Set 8	HFD7d13Ct1	7	13	0.11
	HFD7d13Ct2			0.25
	HFD7d13Ct3			0.51
	HFD7d13Ct4			1

3.3 Soil Structure Interaction on CFHF

Soil Structure Interaction (SSI) of CFHF is one of the main part of this study. The soil- pile and wide bucket- soil are modeled by surface to surface contact. Pile-concrete and pile to wide bucket are modeled by node to node interaction. In pile-soil interaction pile is defined as master surface and the soil surface contact with pile is assigned as slave surface.

Similarly in the wide bucket-soil and wide bucket-pile interactions, the wide bucket is assign as the master surface of each interaction and corresponding slave surfaces are soil and pile respectively. In Pile-concrete interaction, pile is defined as the master surface and concrete assigned as the slave surface. In this present study interface contact is taken as 'hard contact' and there is no separation is allowed.

4. EXPERIMENTAL VALIDATION

In this section numerical modeling (Finite element method) is validated with real experiment. And the computed results obtained from FEA is compared with the experimental result. In this validation, the diameter of monopile (D1) is taken as 8cm m and corresponding embedment length (L) is taken as 25cm. The length, breadth and depth of soil domain are 25 cm x 25 cm x 25cm respectively. The loose soil is used for this study. The monopile is placed at the center of soil domain. The actuator is used to provide the horizontal load to the system and the corresponding horizontal load is measured by the load cell. Fig 7 shows different stages of the experiment

Fig-7 Before and after horizontal loading

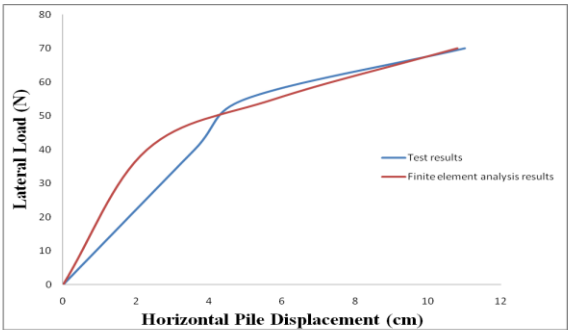
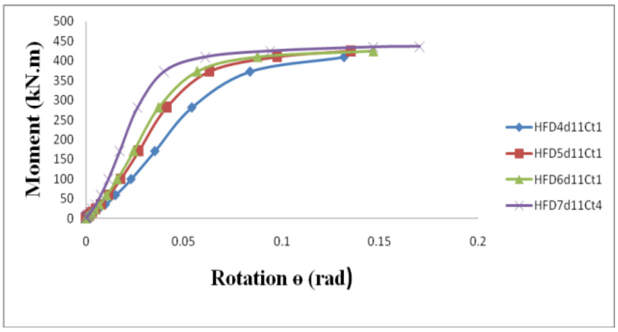


Fig-8 Comparison of test results and FEA results

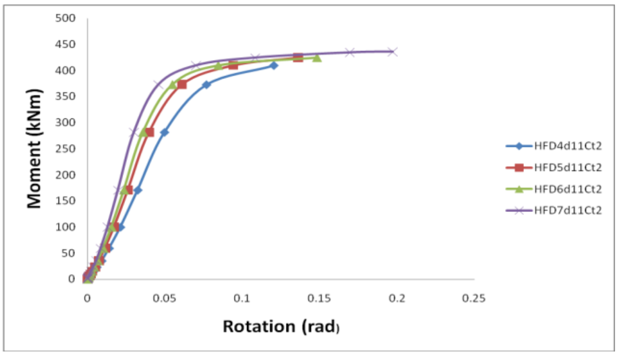
5. RESULT AND DISCUSSION

This chapter is mainly deals with numerical results of CFHF. The results may include lateral displacement and the moment rotation graph. And also investigate its influence in monopile diameter, wide bucket diameter and concrete thickness.

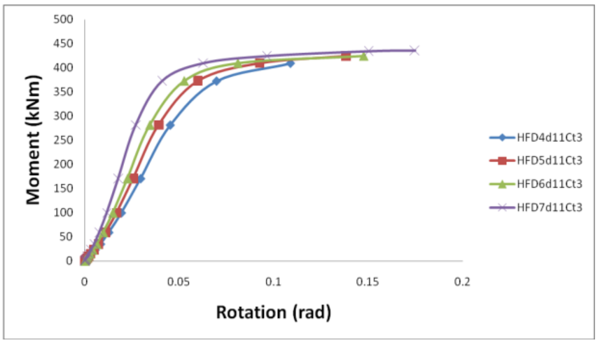
International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 07 | July 2022 www.irjet.net p-ISSN: 2395-0072



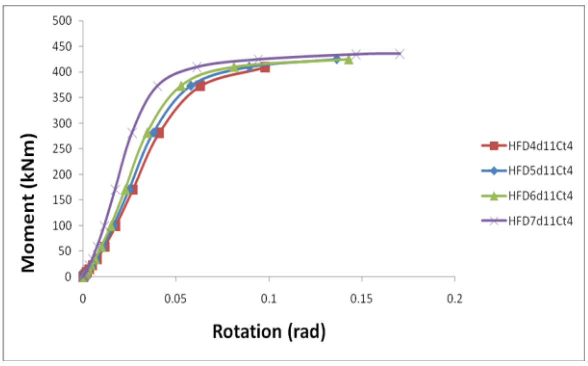
(a)



(b)



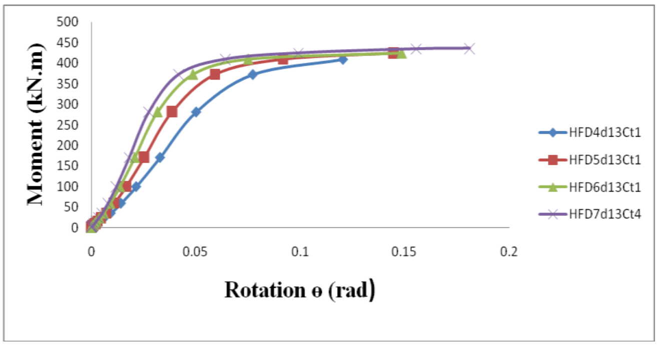
(c)



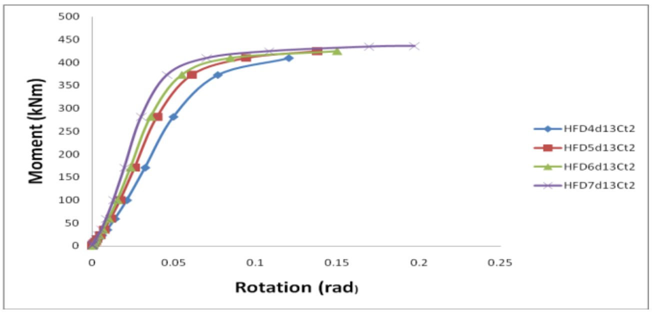
(d)

Fig -9: Moment Rotation graph of 11m Wide bucket

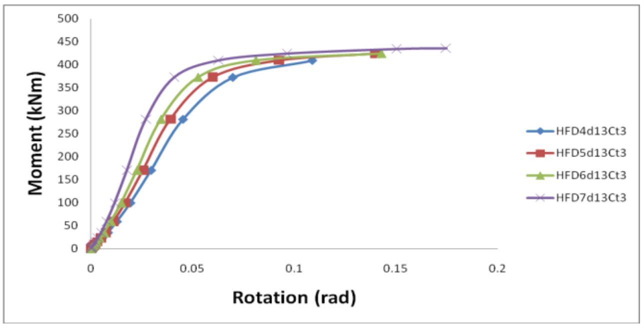
The Fig 9 (a) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.11m and wide bucket diameter is 11m. The Fig 9 (b) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.25m and wide bucket diameter is 11m The Fig 9 (c) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.51m and wide bucket diameter is 11m The Fig 9(d) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 1m and wide bucket diameter is 11m. The Fig 9 shows the ultimate moment carrying capacity of CFHF is increased with increasing monopile diameters. The diameter 7m shows maximum moment bearing capacity, Because the stiffness of the CFHF is directly influenced by diameter of the steel pile. It also reduce the maximum horizontal displacement of CFHF.



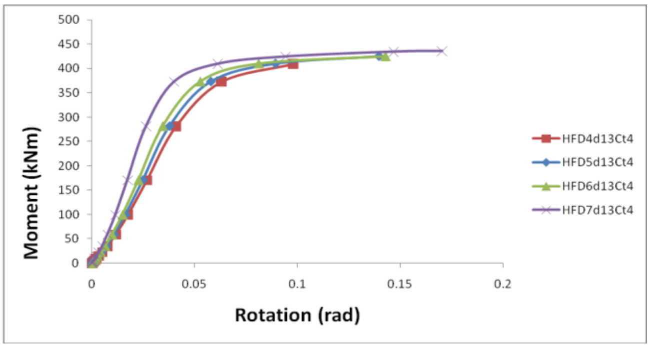
(a)



(b)



(c)



(d)

Fig -10: Moment Rotation graph of 13m wide bucket

The Fig 10 (a) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.11m and wide bucket diameter is 13m. The Fig 10 (b) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.25m and wide bucket diameter is 13m The Fig 10 (c) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 0.51m and wide bucket diameter is 13m The Fig 10 (d) shows the M-R graph of CFHF with different double skin monopile diameter and thickness of concrete is kept as 1m and wide bucket diameter is 13m. The Fig 10 shows the ultimate moment carrying capacity of CFHF is increased with increasing monopile diameters. The diameter 7m shows maximum moment bearing capacity, Because the stiffness of the CFHF is directly influenced by diameter of the steel pile. It also reduce the maximum horizontal displacement of CFHF.

By comparing both Fig 9 and Fig 10, the moment bearing capacity of CFHF will increases with the increasing wide bucket diameters. The thickness of concrete also have the positive influence on the moment bearing capacity. This combination of CFHF will reduce the rotation of the CFHF

6. CONCLUSIONS

From the parametric study, the following conclusions are obtained:

- As the monopile diameter increases and other parameters are keeping constant, then the bearing capacity and rotation of CFHF increases. And the monopile having 4m diameter shows large rotation than 7m diameter.
- The wide bucket diameter also have the positive impact on moment bearing capacity. The variation of wide bucket diameter has less impact on the rotation.
- The concrete thickness has less impact in moment capacity. And having large impact on reduce horizontal displacements.

REFERENCES

[1] Chen ,D., Gao,P., Huang,S., Li,C. and Yu ,X., (2020). "Static and dynamic loading behavior of a hybrid foundation for offshore wind turbines". Marine Structures, Vol.71, pp.102727

[2] Ma,H., and Yang,J.,(2020). " A novel hybrid monopile foundation for offshore wind turbines. Ocean Engineering,Vol. 198, pp.106963

[3] Wang, X., Zeng, X., andLi, J., (2019). "Vertical performance of suction bucket foundation for offshore wind turbines in sand". Ocean Engineering,Vol. 180, pp. 40–48.

[4] Velarde, J., Kramhøft, C., and Sørensen, J.D., (2019). "Global sensitivity analysis of offshore wind turbine foundation fatigue loads". Renewable Energy, Vol.140, pp.177–189.

[5] Ahmed, S.S, and Hawlader, B.,(2016). "Numerical Analysis of Large-Diameter Monopiles in Dense Sand Supporting Offshore Wind Turbines". International Journal of Geomechanics,,pp.04016018 doi:10.1061/(ASCE)GM.1943-5622.0000633

[6] Bhattacharya,S. (2019), " Design of Foundations for Offshore Wind Turbines", Wiley,USA.

[7] Perveen ,R., Kishor, N,. and Mohanty ,S.R.,(2004) " Off-shore wind farm development: present status and challenges". Renew Sustain Energy Rev,Vol.29,pp.780–792.

[8] Achmus,M., Kuo,Y.S., and Abdel-Rahman,K. ,(2009). "Behavior of monopile foundations under cyclic lateral load". Comput Geotech,Vol.36(5),pp.725–35.

[9] Zaaijer,M.,(2002) " Sensitivity analysis for foundations of offshore wind turbines". Sect Wind Energy, TUDelft .

[10] Nikitas, G., Vimalan, N.J., and Bhattacharya, S. (2016). "An innovative cyclic loading device to study long term performance of offshore wind turbines". Soil Dynamics and Earthquake Engineering,Vol.82, pp. 154–160. doi:10.1016/j.soildyn.2015.12.008

[11] RP2A-WSD A Recommended practice for planning, designing and constructing fixed offshore platforms–working stress design–. Paper presented at: Twenty-2000.

[12] Negro, V., López-Gutiérrez, J.S., Esteban, M.D., Matutano, C., (2014). "Uncertainties in the design of support structures and foundations for offshore wind turbines". RenewableEnergy,Vol.63,pp.125–132. doi:10.1016/j.renene.2013.08.041

[13] Cox, J.A.,Bhattacharya, S., and Lombardi, D., Wood Muir Wood, D.M.,(2013). "Dynamics of offshore wind turbines supported on two foundations". Proceedings of the ICE - Geotechnical Engineering,Vol.166(2),pp.159–169. doi:10.1680/geng.11.00015

[14] Wu, X., Hu,Y., Li,Y.,Yang,J., Duan, L., Wang, T., Adcock, T., Jiang, Z., Gao, Z.,Lin, Z.,Borthwick,A., and Liao,S.,(2019). "Foundations of offshore wind turbines: A review". Renewable and Sustainable Energy Reviews,Vol. 104, pp.379–393. doi:10.1016/j.rser.2019.01.012

[15] Hermans, .K, and Peeringa ,J. "Future XL monopile foundation design for a 10 MW wind turbine in deep water",(2016) Technical Report, ECN-E–16-069. The Netherlands: ECN;

[16] Malhotra, S. (2011). "Selection, design and construction of offshore wind turbine foundations." Wind Turbines, I. Al-Bahadly, ed., InTech,Rijeka, Croatia

[17] Thomsen ,K.,(2014). " Offshore wind: a comprehensive guide to successful offshore wind farm installation". Academic Press; .

[18] Castro-Santos ,L.,and Diaz-Casas, V.,(2006). " Floating offshore wind farms". Springer International Publishing.

[19] DNV. "Design of offshore wind turbine structure".(2010) Det Norske Veritas AS.

[20] Lian, J., Chen, F.,and Wang, H., (2014). "Laboratory tests on soil–skirt interaction and penetration resistance of suction caissons during installation in sand". Ocean Eng.Vol. 84,pp.1–13

[21] Dong ,W., Moan, T., and Gao,Z.,(2011). " Long-term fatigue analysis of multi-planar tubular joints for jacket-type offshore wind turbine in time domain". Eng Struct,Vol.33,pp.2002–14

[22] Harris ,J.M., Whitehouse RJS.(2017) " Scour development around large-diameter monopoles in cohesive soils: evidence from the field". J Waterw Port Coast Ocean Eng,Vol.143(5)

[23] De,V.L., De,R. J., Troch ,P.,and Frigaard,P.,(2011) "Empirical design of scour protections around monopile foundations: part 1: static approach". Coast Eng,Vol.58(6),pp.540–53

[24] Achmus ,M., Akdag,C.T., and Thieken,K.(2013). " Load-bearing behavior of suction bucket foundations in sand". Appl Ocean Res,Vol.43(5),pp.157–65.

[25] Wang, X., Yang ,X., and Zeng,X., (2017). "Seismic centrifuge modelling of suction bucket foundation for offshore wind turbine". Renew Energy,Vol.114.